Comparative analysis of Sweep Efficiency of Fluids used for Enhanced Oil Recovery (EOR) method.

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Abstract

Enhanced Oil Recovery helps maximize the oil reserves recovered, extend the field life, and increase the recovery factor. It is an essential tool for firms, helping to maintain production and increasing the returns on older investments. Several techniques are currently used for enhanced oil recovery, each with varying cost, efficiency, and safety implications. Of all the methods, Surfactant EOR has received more attention in recent years, primarily due to its increasing cost-effectiveness against rising oil prices.

Chemical-enhanced oil recovery is a significant EOR method that reduces residual oil saturation by lowering water-oil interfacial tension (surfactant/alkaline) and increasing the volumetric sweep efficiency by decreasing the water-oil mobility ratio (polymer).

This experiment is based on two EOR methods, one of which is the Chemical EOR method. Two fluids based on chemical EOR are prepared and used for injection as EOR fluids. After injecting these fluids, they are compared based on their sweeping capabilities.

Gas injection is one of the oldest oil production methods and is an essential method in the EOR industry. As a technique that yields the highest oil recovery rate, steam injection also has a special place in the oil recovery industry. Yet, it comes second after the most crucial technique of oil recovery, i.e., gas injection. EOR using carbon dioxide reduces the production cost of oil and its price fluctuations, and it is the only technique that has developed steadily in recent years. After steam injection, hydrocarbon injection has rendered the highest rate of oil recovery. Since there have been many efforts to reduce gas combustion, gas injection is considered one of the most essential techniques in the oil recovery industry, both now and in the future.

Keywords: Enhanced Oil Recovery, improve oil Recovery, Production, Sweep Efficiency, LPG, Saline, Benzene.

1. Introduction

In the early days of the petroleum industry, reservoirs were allowed to produce naturally until a particular stage of depletion was reached, generally when the production rates had become uneconomic. This was known as the "primary" production phase. In the secondary phase, the recovery was increased by installing artificial drive (water or gas injection) methods, which were logically known as "secondary recovery methods".

The way to increase oil production further is through the tertiary recovery method or EOR. Although more expensive to employ in a field, EOR can increase production from a well to up to 75% recovery. (Training, n.d.)

There are four main methods of EOR used nowadays in the oil and gas industry, which includes:

- Chemical Flooding.
- Gas Injection.
- Thermal Recovery
- Water Flooding

Chemical injection EOR helps to free trapped oil within the reservoir. This method introduces long-chained molecules called polymers into the reservoir to increase the efficiency of waterflooding or boost the effectiveness of surfactants, which are cleansers that help lower surface tension and inhibit oil flow through the reservoir. However, these chemicals should be designed to withstand the harsh conditions present in the reservoir (e.g., dissolved salts, pH, temperature, presence of bacteria) and increase the efficiency of the process. The combination of the chemicals (polymers, surfactants, alkalis and polymeric surfactants) has shown great potential due to the synergy between them, creating a new spectrum of techniques in chemical Enhanced Oil Recovery. Less than 1% of all EOR methods presently utilized in the US are chemical injections. (Training, n.d.)

Gas injection is a tertiary method of recovery that involves injecting natural gas, nitrogen, or carbon dioxide into the reservoir. The gases can either expand and push gases through the reservoir or mix with or dissolve within the oil, decreasing viscosity and increasing flow. (Training, n.d.)

Thermal recovery introduces heat to the reservoir to reduce the Viscosity of the oil. Steam is often applied to the reservoir, thinning the oil and enhancing its ability to flow. On the other hand, solar-generated steam in EOR involves concentrating solar power technology to produce this steam. Mirrors are used to reflect and concentrate sunlight onto receivers that collect solar energy and convert it to heat. This heat is then used to produce steam from water. One of the principal benefits of using solar power for thermal EOR is the reduced energy costs and carbon footprint of the crude oil produced. Thermal energy has already been deployed in places like Oman, Kuwait, and some fields in California. First applied in Venezuela in the 1960s, thermal recovery now accounts for more than 50% of applied EOR in the US. (Training, n.d.)

Water flooding is one of the economically viable techniques for the recovery of additional oil from mature fields. However, the brine used for water flooding frequently contains suspended fine particles, which can be deposited over the formation injection face and inside the near-wellbore formation to reduce the injectivity of the water-flooding wells. Therefore, it is necessary to predict the economic life of the water injection wells and the treatment frequencies required for the stimulation of the damaged wells. The levelling of reservoir pressure at some withdrawal rate is a measure of water-drive capability. If the aquifer cannot supply sufficient energy to meet desired fluid withdrawal rates while maintaining reservoir pressure, an edge water injection program may be used to supplement natural reservoir energy. This technique should lower the economic limit of the development phase by extending the good life. This is desired as when the financial limit is reached, the well becomes a liability and is abandoned when there is often still a significant amount of unrecoverable oil left in the reservoir. (Ayoub, 2015)

1.1 Sweep Efficiency

Sweep efficiency can be defined by how well displacing Fluid can displace the oil aerially and vertically inside the reservoir. There are two sweep efficiencies: displacement efficiency, which measures the effectiveness of displacing fluid contact with the oil rock in the reservoir and volumetric efficiency, which measures the effectiveness of displacing fluid contact with the oil rock in the reservoir. However, sweep efficiency can be low when the reservoir has fractured, high permeability, and fault. Water breakthroughs and an increase in the water/oil ratio are associated with poor performance and reservoir heterogeneities. Displacement efficiency expresses the efficiency of recovering mobile hydrocarbon. Volumetric sweep efficiency describes the efficiency of fluid recovery in terms of areal sweep efficiency and vertical sweep efficiency. Recovery efficiency is the product of displacement efficiency and areal and vertical sweep efficiencies. (Achim, 2015).

2. Literature Review

The presence of clays and formation fines have a significant impact on a reservoir. They can accumulate and plug the pore throats in a flow channel if left unaddressed during water flooding. This can cause high injection pressure, low sweep efficiency and low oil production. In this paper, the use of nanoparticles in water flooding is addressed, which can significantly improve oil recovery. Water-containing nanoparticles increase the sweep efficiency by fixating the formation fines at their sources, which results in less accumulation and, thus, less choking of the particles at the pore throats. To prove the importance of nanoparticles, a water flooding simulation is conducted with and without nanoparticles in both low and high-permeability reservoirs. In the end, the results were precise. Water flooding without nanoparticles indicates a decrease in linear cumulative oil production. This showed that the fines generated during regular water flooding are detrimental to oil production. Water flooding with nanoparticles showed linear cumulative oil production incrementally. It was concluded that the nanoparticles stabilize clays better than other commercial clay stabilizers. The simulation results showed that the nanoparticle's water flooding increases the oil production rate in both low and high-permeability reservoirs.

2.1 Expansion ratio inflatable plugs

This paper discusses the use of Expansion Ratio Inflatable Plugs to provide zonal isolation and improve sweep efficiency in high-permeability sands. The wells are completed in a 5-spott pattern and produced through the EOR technique. Due to the high viscosity of crude and unfavourable mobility with water, polymer flooding was opted for. Still, a few patterns showed poor sweep efficiency. To overcome this problem, saturation logs were run to locate the poorly swept sand zones and zonal isolation was planned for these zones. A mechanical isolation method was opted to provide temporary zonal isolation before going for Alkaline Surfactant Polymer flooding. Inflatable bridge plugs were used, which were inflated by hydraulic pressure. Since it was on a temporary basis, cement was not run over the plugs. The plugs were deployed through tubing in a 4-1/2'' screen, 7″ casing & 9-5/8″ casing with Coil Tubing. Over 40 jobs of inflate-type plug setting were carried out, which resulted in an additional oil recovery of 2.74 MM bbl. of oil.

2.2 Polymer dispersed system (PDS)

With high reservoir heterogeneity in terms of permeability and fluid properties, significant amounts of water and oil are produced. At water cuts higher than 96–98%, wells turn out to be uneconomical and are shut in or undergo water shut-off treatments. For this reason, shutting off water flow through thief zones in flooded reservoirs to prevent it from entering wells is one of the technical challenges in enhancing oil recovery from mature multi-reservoir oil fields. As the water cut increases, water flow through thief zones must be reduced, along with the amount of water entering the well, to enhance sweep efficiency in lower-permeability portions of the reservoir. A new technology employing polymer dispersed systems (PDS) shuts off formation and injected water flows by increasing flow resistance in thief zones. This process redistributes the energy of the injected water in the reservoir and helps produce oil from upswept zones, thus increasing flooding efficiency and oil recovery.

2.3 Low salinity water flooding

Low salinity water flooding has been a successful tertiary recovery method. Acceptable migration in clay content containing sandstone showed effective results in homogenizing the flow pattern, thus achieving better sweep efficiency. The damage caused by acceptable migration neutralizes the permeability contrast. This causes unflooded zones to take the new lowest resistance path while minimizing fingering.

Modification of the water composition has been shown to be an excellent way to increase oil recovery from both sandstones and carbonates. Compared to other tertiary methods, low salinity water flooding may be one of the cheapest and environmentally friendly approaches. It has been observed that using water with lower saline content or specific ions, the performance of the water-flooding would be influenced by increasing the ultimate oil recovery in both sandstone and carbonate oil reservoirs.

2.4 Dynamic production data

Due to sand heterogeneity and heel-to-toe effect, horizontal wells suffer from uneven flow profiles and premature coning effects. The sweep efficiency is also limited by increasing the length of horizontal wells. The optimal well length depends on reservoir heterogeneity. A new method was established, which calculates sweep efficiency of horizontal wells based on dynamic production data and is more economical and efficient.

2.5 Foam injection

The foam injection was introduced because of the increasing reinjection of gas, which causes a disturbance in the gas-oil ratio. The foam injection is as compatible as SAG, but due to massive gas injection and lack of enough water sources to comply with the large volume required by the SAG foam technique, a new foam deployment technique based on injection of the foamier chemical dispersed in the gas stream was developed. The effectiveness of foam as a technology to improve sweep efficiency in naturally fractured dominated systems was proved.

2.6 Formation heterogeneity

Poor sweep efficiency of reservoir development in the vertical and horizontal directions is caused by the formation of vertical heterogeneity and separate filtration pathways. The factors that determine the effectiveness of reserves recovery include sweep efficiency, which involves the identification of fluid parameter pathways, residual oil identification, water flooding optimization, and squeezing.

2.7 Polymer gel technology

Polymer gels are a better option than cementation due to their greater penetration in the formation and easy removal by water recirculation. It behaves as a flow-diverting or blocking agent in high permeability reservoirs as it reduces fluid channelling. Specific gel properties need to be controlled for the gel to work efficiently, such as salinity, pH, and hardness of water during gel preparation. Thus, polymer gel technology appears to be economically feasible for redirecting water flow in the reservoir and improving oil recovery.

2.8 Gas flooding

Deep reservoirs are needed to achieve miscibility with light oils at very high pressure. A steeply dipping reservoir is desired to permit gravity stabilization of the displacement, which has an unfavourable mobility ratio. Viscous fingering in the reservoir is a common problem that results in poor vertical and horizontal sweep efficiency, and corrosion in the production system is also common during gas flooding. Injected gas must be separated at the production facility before being injected into the reservoir again. Large amounts of gas are often required for successful recovery.

2.9 In-situ combustion

Combustion sustainability in the reservoir is a problem and very difficult to control if sufficient coke is not deposited. Oil saturation and porosity must be high to minimize heat loss in the rock matrix. Sweep efficiency is low in thick reservoirs; it is better to use it in thin pay zones at a shallow depth. Adverse mobility ratio, early breakthrough of the combustion front, corrosion, and environmental issues are common problems with in-situ combustion.

3. Methodology

The experiment is performed by replicating a reservoir with a producer and an injection well. A total of 4 models were made of a similar sound pattern. Three of these models are based on chemical injection methods, and one of the models is based on gas injection.

3.1 Density Calculation using Mud Balance

A mud balance is a device that measures the density (weight) of mud, cement, or other liquids or slurry. A mud balance consists of a fixed-volume mud cup with a lid on one end of a graduated beam and a counterweight on the other end. A slider-weight can be moved along the beam, and a bubble indicates when the beam is level. (Figure 1)

Figure 1 Equipment used to measure the mud Density.

3.1.1 procedure of calculating specific gravity

Specific gravity is a dimensionless unit that compares the density of a substance to the density of a reference substance, typically water, to a particular temperature. For liquids and solids, water is commonly used as the reference substance, and the density is usually measured at a standard temperature, such as 4 degrees Celsius (39.2 degrees Fahrenheit). Since specific gravity is a ratio of densities, it is a dimensionless quantity.

The procedure to calculate the API of the oil is defined below:

i. The cup of the mud balance is cleaned and dried to get rid of any dust particles.

ii. Oil is filled in the cup to the very top.

iii. The lid of the cup is placed on top.

iv. Any excess oil that spills after placing the lid is cleaned off to avoid any miscalculations.

v. The apparatus is placed in its container over a fulcrum.

vi. The slider weight on the balance arm of the mud balance is moved to balance the apparatus.

vii. The bubble level on the scale must be in the middle.

viii. After adjusting the weight and getting the balance arm steady, note the specific gravity of the oil from the scale of the mud balance.

3.1.2 Api gravity calculation

API gravity, or the American Petroleum Institute gravity, is a measure of how heavy or light a petroleum liquid is compared to water. It is a scale developed by the American Petroleum Institute to quantify the relative density of crude oil and other liquid hydrocarbons. Unlike specific gravity, API gravity is expressed in degrees.

The API gravity scale is inversely related to the density of the liquid. Lighter, less dense liquids have higher API gravity values, while heavier, more dense liquids have lower API gravity values.

API gravity of oil can be calculated by using the formulas given below:

$$API = \frac{141.5}{SG} - 131.5 \quad Eq\ 1$$

$$API = \frac{141.5}{0.92} - 131.5$$

$$API = 21.9^{\circ} \quad Eq\ 2$$

From the calculation, it was obtained that the API gravity of the oil is found to be 21.9, which implies that the type of oil is heavy oil.

3.2 Formation grain size analysis

Formation grain size analysis is a process used in geology to study and characterize the size distribution of grains or particles within a rock formation. The grain size of sedimentary rocks provides valuable information about the depositional environment, transportation history, and geological processes that formed the rocks. Several methods are commonly employed for grain size analysis, and these can be broadly categorized into field and laboratory techniques.

There are two types of techniques used for analyzing:

i. Field Techniques
ii. Laboratory Techniques

Grain size analysis is crucial in understanding the depositional history of sediments, interpreting paleoenvironments, and making predictions about the rock's mechanical properties. Different methods are chosen based on the size range of interest and the level of detail required for the analysis. In this research, we will focus on and use laboratory techniques to analyze the formation grain size. The desired length of the grains of the formation was taken with the help of a Sieve Shaker.

3.2.1 Sieve shaker

Sieve shakers are used to separate and determine the size of particles. A typical sieve shaker separates particles by passing them through a series of chambers with mesh filters and agitating the sample to obtain complete separation.

3.2.2. procedure for the measurement of Grain sizes

The procedure to obtain the desired grain size is defined below:

i. The sandstone grains were placed in the apparatus's top tray.

ii. The sieve shaker was turned on, and the device ran for an hour. (Figure 2- Left)

iii. After an hour of shaking the grains, the shaker stopped, and the grains were separated into different trays of sieves of various sizes.

iv. The grains of the sandstone formation were taken from sieve no.12 of, size 1700 microns with an opening size of 1.70 mm, and sieve no.16 of size 1100 microns with an opening size of 1.10 mm. (Figure 2- Right)

Figure 2 Measurement of Grain Size using Sieve shaker

3.3 Calculation of Rock Porosity

Rock porosity refers to the percentage of void space (pore space) within a rock, expressed as a fraction of the total rock volume. It is a critical property in geology and petroleum engineering because it affects the storage and movement of fluids, such as water, oil, and gas, within subsurface rock formations. Porosity is a critical factor in determining the reservoir potential of rocks and their ability to store and transmit fluids.

The porosity of the formation is calculated through the following method:

i. The volume of the container is calculated to be 1540 cubic centimetres or 1540 ml.

ii. The volume of liquid in the container without formation is 1540 ml, which is also the bulk volume.

iii. The volume of liquid with the formation is found to be 300 ml, which is also the pore volume.

iv. With the help of the following formula, the porosity of the formation was calculated:

$$\emptyset = \frac{Pore\ Volume}{Bulk\ Volume} \times 100 \qquad Eq\ 3$$

$$\emptyset = \frac{300}{1540} \times 100$$

$$\emptyset = 19.4\% \qquad Eq\ 4$$

The results of the testing and experiments show that the porosity of the formation is found to be 19.4%.

It's important to note that high porosity alone does not guarantee good reservoir quality. The connectivity of pores and the permeability (ability of fluids to flow through the rock) are also crucial factors in determining the effectiveness of a rock as a reservoir. The combination of porosity and permeability influences the overall reservoir quality of a rock formation.

3.4 Calculation of Viscosity

Viscosity is a measure of a fluid's resistance to deformation or flow. In simpler terms, it describes how easily a fluid can move. Fluids with high viscosity flow more slowly than fluids with low Viscosity. Viscosity is a crucial property in various fields, including physics, engineering, and fluid dynamics.

3.4.1 Viscometer

The OFITE Model 800 viscometer determines the flow characteristics of oils and drilling fluids in terms of shear rate and shear stress over various time and temperature ranges at atmospheric pressure. Speeds are easily changed with a control nob, and shear stress values are displayed on a lighted magnified dial for ease of reading. (Figure 3)

Figure 3 Equipment used to calculate the Fluid Viscosity

3.4.2 procedure to calculate Oil Viscosity

The Viscosity of oil is a critical property that influences its flow behaviour, lubricating efficiency, and performance in various applications. Oil viscosity is a measure of the oil's resistance to flow or deformation. It is essential in the fields of lubrication, hydraulic systems, and petroleum engineering. There are different ways to classify and measure oil viscosity, and it plays a crucial role in selecting the right oil for specific applications.

The procedure for calculating oil viscosity is as follows:

a. Fill the cup of Viscometer with 400 ml of oil.

b. Put the nob of the Viscometer to stir to get rid of any air bubbles or gas bubbles in the oil.

c. Turn the north friend in RPMS, check through the magnifier dial, and note the Viscosity.

Table 1 shows the results of the obtained Viscosity of the oil at different RMP readings:

Table 1 Viscosity measurement at various RMP readings

S#	RPM Value(s)	Viscosity (cP)
1	6	4.5
2	30	18
3	60	36
4	100	60
5	200	118
6	300	175.5
7	600	324

Figure 4 shows the relationship between the obtained measure of the Viscosity of oil used in this experiment at various numbers of RMP in the equipment.

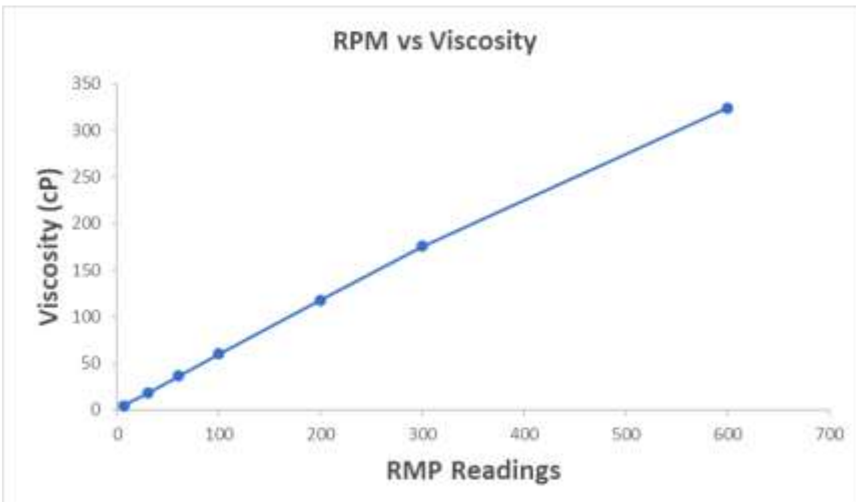

Figure 4 Graph chart between RMP and Viscosity behaviour

Figure 5 shows the RMP readings at which the Viscosity of oil is calculated. Here, the highest values, i.e. 300 and 600 RMP reading values, are displayed.

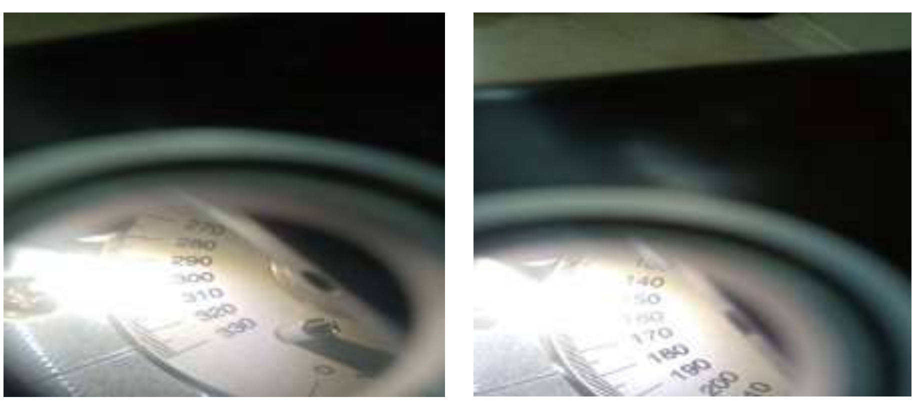

Figure 5 Viscosity calculation of Fluid at 600 and 300 RMP Respectively

3.4.3 Calculation of Plastic and Apparent Viscosity

Plastic Viscosity (PV) can be defined as the resistance offered by a fluid to flow freely. The formula to calculate plastic viscosity is given below:

$$\mu = 600r - 300r \quad Eq\ 5$$

$$\mu = 324 - 175.5$$

$$\mu = 148.5\ cp \quad Eq\ 6$$

Apparent Viscosity is the shear stress applied to a fluid divided by the shear rate. The formula for the calculation of apparent Viscosity for oil is given below:

$$\mu = \frac{600r}{2} \quad Eq\ 7$$

$$\mu = \frac{324}{2}$$

$$\mu = 162\ cp \quad Eq\ 8$$

3.4.4 Viscosity calculation for saline water

Following are the values of Viscosity measured at different RPMS:

a. At 200 RPMS, the Viscosity is found to be one centipoise.

b. At 300 RPMS, the Viscosity is found to be 1.5 centipoise. (Figure 6)-left.

c. At 600 RPM's, the Viscosity is found to be 2.5 centipoise. (Figure 6)-right

Figure 6 Viscosity calculation of Fluid at 600 and 300 RMP Respectively

3.4.5 Calculation of Plastic and Apparent Viscosity of Saline Water

The formula for the calculation of the plastic Viscosity of saline water is given below:

$$\mu = 2.5 - 1.5$$

$$\mu = 1\ cp \quad Eq\ 9$$

The formula for calculation of the apparent Viscosity of saline water is given below:

$$\mu = \frac{2.5}{2}$$

$$\mu = 1.25\ cp \quad Eq\ 10$$

3.4.6 Viscosity calculation for sodium stearate solution

Following are the values of Viscosity measured at different RPMS:

a. At 200 RPMS, the Viscosity is found to be 2.5 centipoise.

b. At 300 RPMS, the Viscosity is found to be three centipoises.

c. At 600 RPM, the Viscosity is found to be six centipoises.

3.4.7 Calculation of Plastic and Apparent Viscosity of sodium stearate solution

The formula for the calculation of the plastic Viscosity of sodium stearate solution is given below:

$$\mu = 6 - 3$$

$$\mu = 3\ cp \qquad Eq\ \ 11$$

The formula for calculation of the apparent Viscosity of sodium stearate solution is given below:

$$\mu = \frac{6}{2}$$

$$\mu = 3\ cp \qquad Eq\ \ 12$$

3.5 Experimental model description

A designed model is required to perform an experiment on EOR. In which injection and producing wells are being developed. The formation design is of sandstone. Following is the description of how the model is made:

a. The model is made of a plastic box with a removable top.

b. Two holes are created diagonally on the corners of the top.

c. Rubber pipes are passed through those holes, simulating the wells.

d. The pipe pushed to the bottom of the box is called the injector.

e. The pipe placed slightly above is called the producer.

f. The reservoir rock is composed of sandstone.

g. The chemical injection process is performed through syringes.

h. The gas injection process was performed through UCP-P.

3.6 Working mechanism for chemical injection

The reservoir model is assembled airtight to stop any fluid leak. Oil is injected through the injector well with the help of a syringe in a certain amount to simulate residual oil (Figure 7). The oil is allowed to settle, and the experiment starts. The fluids are injected with different syringes to keep the fluid properties from changing. The fluids are pumped through the syringes until the oil begins to be produced from the producer well. The produced fluids are collected in a measured flask. The experiment was conducted to observe how efficiently a fluid sweeps the oil across the reservoir.

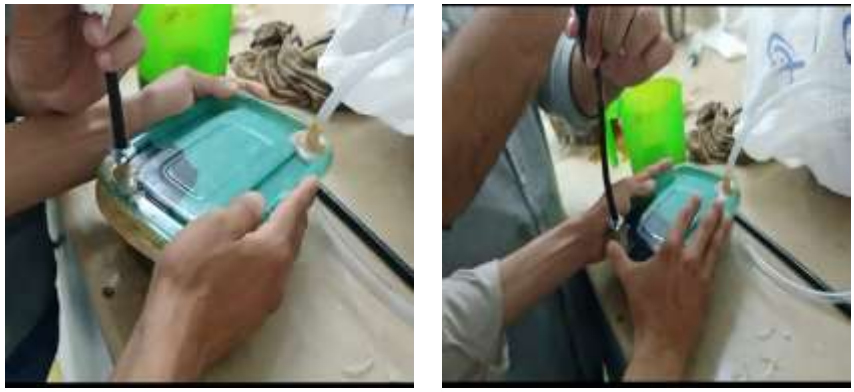

Figure 7 Reservoir model having an injection and producing well for liquid Injection

3.7 Working mechanism for gas/air injection

The reservoir model is assembled airtight to stop any fluid leak. Oil is injected through the injector well with the help of a syringe in a certain amount to simulate residual oil (Figure 8). The oil is allowed to settle, and the experiment starts. The fluids are injected with different syringes to keep the fluid properties from changing. A Process Control Unit-Pressure (UCP-P) is used to inject air and gas into the model (figure 4.0). The produced fluids are collected in a measured flask. The experiment was conducted to observe how efficiently a fluid sweeps the oil across the reservoir.

Figure 8 Reservoir model having an injection and producing well for Gas Injection

3.8 Fluids Used for Enhanced Oil Recovery (EOR)

Various fluids are being used for evaluation through an experiment in this research. These EOR fluids are fluids that are injected into the reservoir to push the residual oil towards the production well. The purpose of fluids is to change the properties of oil to make it mobile so it can quickly move the residual oil or the heavy oil towards the wellbore.

Four types of injection fluids are used in this experiment. Those include:

1. Saline solution. (Chemical/Liquid Injection)
2. Alkyl-benzene-sulphonate solution. (Chemical/Liquid Injection)
3. Air. (Gas Injection)

4. CO2/N2. (Gas Injection)

A saline solution is a mixture of salt and water. For this experiment, 80 grams of table salt (NaCl) are added and mixed in 1 liter of water.

Alkyl-benzene-sulphonate solution is a mixture of detergent and water. For this experiment, 80 grams of detergent powder is added and mixed in 1 litre of water.

Air is a mixture of different gases, mainly comprised of 78% nitrogen, 21% oxygen and 1% of other gases. For this experiment, air is collected through a compressor in a tank installed on UCP-P.

Liquified petroleum gas (LPG) is a flammable mixture of hydrocarbon gases such as propane and butane. For this experiment, LPG is collected in a cylinder for gas injection.

3.9 Designing of Models for the injection of fluids as EOR Fluid

Four models are being designed and used for the injection of four different fluids used as EOR fluid in the reservoir. The parameters of each model (considered a reservoir) are the same, but the injection fluids are being changed.

3.9.1 MODEL 1 with Saline Solution as EOR Fluid

In model 1, we inject saline water into our formation and observe how efficiently it sweeps the residual oil in our formation. Saline Solution is a mixture of salt and water. One liter of this fluid is used for this experiment.

3.9.1.1 Experimental procedure

The model is assembled by connecting an injector and a producer pipe through the top of the box. The model is then filled with sandstone formation and sealed tightly to ensure there is no leakage. The injector pipe is connected to a syringe to pump the oil and the injection fluid into the formation. 150 ml of oil is injected into the formation to simulate "RESIDUE OIL". After the oil has settled into the formation, saline water is injected into the formation to sweep the oil towards the producer pipe (Figure 9). After injecting 1 kg of air, the produced fluids are measured.

Figure 9 Performing an experiment and injection of Saline Solution as EOR Fluid

3.9.1.1 Observation and outcome of the experiment performed on Model 1

After performing an experiment, it was observed that after the injection of saline water from the injection well of the model, some quantity of oil is being drained out from the reservoir model, as shown in Figure 10. It is clear from the picture that the maximum amount produced is oil injected oil, and a very small amount of oil is produced. Residue oil injected into the reservoir is 150ml, of which 6.66% is produced after performing an experiment. After injecting saline water into the reservoir, 6.66% of the residual oil is recovered, which is slightly better than a simple water injection.

Figure 10 Quantity of Produced Residue oil from the designed model after injection of Saline Water EOR Fluid

3.9.2 Model 2 with Alkyl-Benzene-Sulphonate Solution as EOR Fluid

In model 2, we inject an alkyl-benzene-sulphonate solution and observe how efficiently it sweeps the residual oil in our formation.

Detergents (alkyl-benzene-sulphonate) are surfactants since they can decrease the surface tension of water. Their dual nature facilitates the mixture of hydrophobic compounds (like oil and grease) with water. One liter of this fluid is used for this experiment.

3.9.2.1 Experimental procedure

The model is assembled by connecting an injector and a producer pipe through the top of the box. The model is then filled with sandstone formation and sealed tightly to ensure there is no leakage. The injector pipe is connected to a syringe to pump the oil and the injection fluid into the formation. 150 ml of oil is injected into the formation to simulate "**RESIDUE OIL**". After the oil has settled into the formation, soap water is injected into the formation to sweep the oil towards the producer pipe (Figure 11). After injecting 1 litre of EOR fluid, the produced oil is measured.

Figure 11 Performing an experiment and injection of Alkyl-Benzene-Sulphonate Solution as EOR Fluid

3.9.2.2 Observation and outcome of the experiment performed on Model 2

After performing an experiment using Alkyl-Benzene-Sulphonate as injection fluid for EOR, it was observed that after the injection of saline water from the injection well of the model, some quantity of oil is being drained out from the reservoir model is shown in Figure 12. It is clear from the picture that the maximum amount produced is injected with Alkyl-Benzene-Sulphonate, and a low amount of oil is produced. However, this amount of produced oil is better than the amount of oil produced using 3.9.1 MODEL 1 with Saline Solution as EOR Fluid. Residue oil injected in the reservoir is of the same amount used in Model 1, i.e. 150ml, of which 26.66% is produced after performing an experiment. After injecting Alkyl-Benzene-Sulphonate into the reservoir, 26.66% of the residual oil is recovered, which is slightly better than the Saline Solution injection.

Figure 12 Quantity of Produced Residue oil from the designed model after injection of Alkyl-Benzene-Sulphonate as EOR Fluid

3.9.3 Model 3 with Air as an EOR Fluid

In model 3, we are injecting air and observe how efficiently it sweeps the residual oil in our formation. Air is a mixture of gases, including nitrogen and oxygen. 1 kg of air is injected for this experiment.

The Computer Controlled Process Control Unit for the Study of Pressure (Air), "UCP-P", consists of a compressed air duct whose flow is controlled by a pneumatic valve (Figure 13). The air is supplied through the air inlet, and it can be diverted with two pressure regulators toward the circuit, which controls the valve or the circuit, where the pressure and flow are controlled. The valve control circuit is composed of an I/P converter, which transforms the electrical signal sent by the computer into a pneumatic signal, and a manometer is placed between the I/P converter and the valve. The main circuit, whereby the flow and pressure will be controlled, is composed of an absolute pressure sensor and a manometer to control the pressure, an orifice plate with a differential pressure sensor and a flowmeter to control the flow and four manual valves to introduce disturbances in the system and to change its configuration adding an air tank to the duct for the study of the volume effect in the control system. The Process control unit used for this experiment is from a Spanish company called "EDIBON". Edibon is a worldwide benchmark company with 40 years of experience in teaching equipment for engineering and technical education.

Figure 13 Computer Controlled Process Control Unit for the Study of Pressure (Air)

3.9.3.1 Experimental procedure

The model is assembled by connecting an injector and a producer pipe through the top of the box. It is then filled with sandstone formation and is then sealed tightly to ensure no leakage. The injector pipe is connected to a syringe to pump the oil and the injection fluid into the formation. 240 ml of oil is injected into the formation to simulate "RESIDUE OIL". After the oil has settled into the formation, the air is injected into the formation through a Process Control Pressure (UCP-P), which is further connected to an air compressor. The compressor is turned on, and the air is pumped at an inlet pressure of 35 psi through the UCP-P (Figure 14)-left. The pressure is controlled through valves (Figure 14)-right. 1 kg of air is injected into the reservoir model, and the results are observed.

Figure 14 Performing an experiment and injection of Air n as EOR Fluid

3.9.3.2 Observation and outcome of the experiment performed on Model 3

After performing an experiment using Air as injection fluid for EOR, it was observed that after the injection of Air from the injection well of the model, a huge amount of oil (almost half of the residue oil) was drained out from the reservoir model and is shown in Figure 15. It is clear from the picture that the maximum amount produced is of oil. However, this amount of produced oil is way much better than the amount of oil produced using 3.9.1 MODEL 1 with Saline Solution as EOR Fluid and 3.9.2 Model 2 with Alkyl-Benzene-Sulphonate Solution as EOR Fluid. Residue oil injected in the reservoir amounts to 250ml (because of the injection of gas/air), of which 56.25% of oil is produced after performing an experiment. After injection of air as EOR fluid in the reservoir at high pressure, about 56.25% of the residual oil is recovered, which is much better than the liquid fluids used as EOR fluid, as shown in Model 1 and Model 2.

Figure 15 Quantity of Produced Residue oil from the designed model after injection of Air as EOR Fluid

After the injection of air into the reservoir, 56.25% of the residual oil is recovered, which is more than half the total residual oil.

3.9.4 Model 4 with Liquified Petroleum Gas (LPG) as an EOR Fluid

In model 4, we inject LPG and observe how efficiently it sweeps the residual oil in our formation. Liquified petroleum gas is a flammable mixture of hydrocarbon gases. 1 kg of LPG is injected for this experiment.

3.9.4.1 Experimental procedure

The model is assembled by connecting an injector and a producer pipe through the top of the box. It is then filled with sandstone formation and is then sealed tightly to ensure no leakage. The injector pipe is connected to a syringe to pump the oil and the injection fluid into the formation. 240 ml of oil is injected into the formation to simulate "RESIDUE OIL" (Figure 16). After the oil has settled into the formation, the air is injected into the formation through a Process Control Pressure (UCP-P), which is further connected to a cylinder filled with LPG. The cylinder is turned on, and LPG is pumped at an inlet pressure of 35 psi through the UCP-P. The pressure is controlled through valves. 1 kg of LPG is injected into the reservoir model, and the results are observed.


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Figure 16 Performing an experiment and injection of LPG as EOR Fluid

3.9.4.2 Observation and outcome of the experiment performed on Model 4

After performing an experiment using LPG as injection fluid for EOR, it was observed that after injection of LPG from the injection well of the model, a maximum amount of oil (more than half of the residue oil) was drained out from the reservoir model and is shown in Figure 17. It is clear from the picture that the maximum amount produced is of oil. During injection of LPG, it dissolves into the oil and decreases its viscosity, which results in greater oil mobility. However, this amount of produced oil is the highest amount of oil produced compared to 3.9.1 MODEL 1 with Saline Solution as EOR Fluid, 3.9.2 Model 2 with Alkyl-Benzene-Sulphonate Solution as EOR Fluid and 3.9.3 Model 3 with Air as an EOR Fluid. Residue oil injected in the reservoir amounts to 250ml (because of the injection of gas/air), of which 62.5% of oil is produced after performing an experiment. After injection of air as EOR fluid in the reservoir at high pressure, about 62.5% of the residual oil is recovered, which is much better than the liquid fluids used as EOR fluid, as shown in Model 1, Model 2, and Model 3.

Figure 17 Quantity of Produced Residue oil from the designed model after injection of LPG as EOR Fluid

4. Results and comparison

4.1 Results of an experimental work performed on Model 1

In model 1, we injected saline water as an EOR fluid into our formation to observe its sweep efficiency. We took 80 grams of sodium chloride in one litre of water. The initial oil in place was 150 ML. After injecting the ER fluid into the formation at an inlet pressure of 10ML per second, we observed that the oil recovery was 6.66% of the total oil in place. The recovered oil is in very small quantities, and the EOR fluid is found to be uneconomical.

4.2 Results of an experimental work performed on Model 2

In model 2, we injected an alkyl-benzene-sulphonate solution into our formation to observe its sweep efficiency. We took 80 grams of alkyl-benzene-sulphonate in one litre of water. The initial oil in place was 150ML. After injecting the EOR fluid into the formation at an inlet pressure of 10ML per second, we observed that the oil recovery was 26.66% of the total oil in place. The quantity of the recovered oil is somewhat satisfactory or acceptable.

4.3 Results of an experimental work performed on Model 3

In Model 3, we injected 1 kilogram of Air through the process control unit, which was further connected to an air compressor. The initial oil in place is 240ML. After injecting the EOR fluid through the reservoir model, we observed that oil recovery was 56.25%. And it can be economical and good production.

4.4 Results of an experimental work performed on Model 4

In model 4, we injected 1 kilogram of LPG through a process control unit, which was further connected to a cylinder. The initial oil in place is 240ML. After injecting the EOR fluid through the reservoir model, we observed that oil recovery was 62.5%. By injecting LPG, the oil recovered is in huge quantity, and this shows the effectiveness of LPG usage as an EOR fluid.

5. A comparative analysis of the sweep efficiency of four fluids was used in this experiment as an EOR fluid.

In this research, a total of four different fluids are used as EOR fluid for the injection and then production of residue oil. However, of these four fluids, two fluids are in liquid form, and the other two are in gaseous form. Therefore, in this research, comparative analysis is divided into two different categories: liquid injection (i.e. saline water and Alkyl-Benzene-Sulphonate) and other is gaseous injection (i.e. Air and LPG).

From Table 2, it is clear from the results that injection of alkaline Benzie has more and better sweep efficiency compared with saline or simple water. This is because Alkyl-Benzene-Sulphonate has some mixture of additives that enable this EOR fluid to push oil towards production well and produce it in a better amount than Saline water.

Table 2 Comparative analysis of sweep efficiency of liquid fluid as EOR

S#	Properties	Model 1	Model 2
1	EOR Fluids	Saline Water	Soap Water
2	Formation	Sandstone	Sandstone
3	Additives (Concentration)	80 Gm NaCl	80 Gm Sodium Stearate
4	Initial Oil in Place	150 Ml	150 Ml
5	Recovery	6.66%	26.66%
6	Level Of Produced Oil		

Also, from Table 3, it is clear from the results that injection of Alkyl-Benzene-Sulphonate has more and better sweep efficiency compared with saline or simple water. This is because Alkyl-Benzene-Sulphonate has some mixture of additives that enable this EOR fluid to push oil towards production well and produce it in a better amount than Saline water.

Table 3 Comparative analysis of sweep efficiency of gaseous fluid as EOR

S#	Properties	Model 3	Model 4
1	EOR Fluids	Air	LPG
2	Formation	Sandstone	Sandstone
3	Quantity Of Gas	1 Kg	1 Kg
4	Injection Pressure	35 Psi	35 Psi
5	Initial Oil in Place	240 Ml	240 Ml
6	Recovery	56.25%	62.5%
7	Level Of Produced Oil		

Conclusion

In this research work, the focus is to analyze the comparative analysis of sweep efficiency using different fluids in injection. In this research, two liquid fluids and two gaseous fluids are used for injection and analysis of the sweep efficiency of these four fluids.

Injection of Liquid (i.e. Saline Water and Alkyl-Benzene-Sulphonate) as an EOR Fluid

Liquid injection was carried out in this research by using saline water and alkaline benzene. The injection of these liquids is under similar circumstances, such as the same reservoir type, the same type of residue oil, the same amount of residue oil and the same injection pressure. Therefore, we can compare the sweep efficiency with these fluids. From these experiments, we concluded that:

After comparing the results of these experiments performed on a laboratory scale from model 1 and model 2, we have concluded that:

1. The sodium stearate solution is more efficient in sweeping the residual oil than the saline solution.
2. The water breakthrough in model 1 was very early as compared to model 2.
3. The oil recovery is much greater with sodium stearate solution than with saline solution.
4. The saline solution is found to be inefficient and uneconomical.

Injection of Gaseous fluids (i.e. Air and Liquefied Petroleum Gas) as an EOR Fluid

Injection of Gaseous fluid was carried out in this research by injecting Air and LPG. The injection of these fluids was conducted at similar parameters, such as the same reservoir type, the same type of residue oil, the same amount of residue oil in the reservoir and the same injection pressure. Therefore, we can compare the sweep efficiency with these fluids.

After comparing the results of these experiments performed on a laboratory scale from model 3 and model 4, we have concluded that:

1. The LPG is more efficient in sweeping the oil than Air.
2. There is a big difference in the recovery percentages of Air and LPG.
3. LPG dissolves in the oil and makes it less viscous.
4. A decrease in viscosity increased the mobility of the oil.

Recommendations

For future work, it can be recommended that this experiment be performed on a modified reservoir model. It can also enhance the understanding by using more injection fluids of liquid and gasses. EOR is highly recommended to be performed in shale formations and highly tight reservoirs; therefore, using this method and models, we can modify it by changing reservoir type and injection fluid type with all its parameters, such as injection rate, reservoir pressure, temperature, and reservoir compaction effect.

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